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13. ABSTRACT (Maximum 200 words)

The funding obtained from this grant was used to purchase a tunable femtosecond laser system for use in the investigator's research in quantum and nonlinear optical imaging. The funding arrived during the first year of the investigator's ARO project on this topic, and the availability of this new facility has contributed greatly to this research project. During the past year, we made the final selection of the laser system, placed the order for the laser, and installed it in our laboratory. The facility is now fully operational. The laser system was selected both because of its immediate relevance to our ARO-sponsored research program and because it is a very versatile laser system that can be tailored to a wide range of immediate and future applications. The short pulse duration produced by this system allows us to study high-intensity effects through use of only modest pulse energies. In this manner, we can avoid problems associated with laser damage and thereby be able to make use of the weaker but more versatile third-order nonlinear optical response for the generation of entangled and other quantum-correlated beams of light. The wavelength tunability of this laser system will allow us to make use of structural resonances in various material systems (such as PBG materials) to allow the large nonlinear response of such materials to be used for the generation of quantum states of light. This equipment will be useful for the education of a diverse group of students.

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Instrumentation for Quantum and Nonlinear Optical Imaging

Robert W. Boyd, University of Rochester

Final Report -- November 9, 2003
US Army Research Office, Research Triangle Park, NC
Performance Period: June1, 2002 through May 31, 2003

Overview

The funding obtained from this grant was used to purchase a tunable femtosecond laser system for use in the investigator's research in quantum and nonlinear optical imaging. The funding arrived during the first year of the investigator's ARO project on this topic, and the availability of this new facility has contributed greatly to this research project. During the past year, we made the final selection of the laser system, placed the order for the laser, and installed it in our laboratory. The facility is now fully operational. The specifications of the new laser system are spelled out in detail below. The laser system was selected both in terms of its immediate relevance to our ARO-sponsored research program and because it is a very versatile laser system that can be tailored to a wide range of immediate and future applications. The short pulse duration produced by this system allows us to study high-intensity effects through use of only modest pulse energies. In this manner, we can avoid problems associated with laser damage and thereby be able to make use of the weaker but more versatile third-order nonlinear optical response for the generation of entangled and other quantum-correlated beams of light. The wavelength tunability of this laser system will allow us to make use of structural resonances in various material systems (such as PBG materials) to allow the large nonlinear response of such materials to be used for the generation of quantum states of light. This laser system is very versatile and will meet many of the investigator's need in the field of ultrafast nonlinear. This equipment will also be useful for the education of a diverse group of students, as described below.

Equipment Purchased

Spectra-Physics Femtosecond laser system consisting of

(a) Millenia all solid state pump laser producing 5 watts cw at 532 nm

(b) Upgrade of an existing Tsunami femtosecond laser to produce required output specifications: less than 50 fs pulse duration, 76 MHz pulse repetition rate, 13 nJ per pulse, 1 W average power, tunable from 700 to 980 nm.

(c) Spitfire Ti:Sapphire regenerative amplifier producing pulses shorter than 130 fs with 1 mJ per pulse at a 1 kHz repetition rate. tunable from 750 to 840 nm.

(d) Evolution all-solid state intracavity-frequency doubled pulsed laser to pump with Spitfire amplifier.

(e) Femtosecond optical parametric amplifier (OPA) capable of continuous tuning from 1.1 to 3.0 micrometers and producing output pulses of less than 130 fs duration.

(f) Harmonic converter for the output of the OPA, capable of producing the second and fourth harmonics.

(g) Single-shot autocorrelator for characterizing the pulse duration of this system.

The total price of this system is $296,500. Of this amount, $170,000 was charged to ARO and the remainder was charged to an AFOSR equipment account.

Participating Scientific Personnel

Matthew King – Undergraduate

Ryan Bennink -- PhD Student, will graduate early 2004

Sean Bentley -- PhD Student, will defend late 2003; accepted faculty position at Adelphi University

Matthew Bigelow – PhD Student, will graduate within next year

John Heebner -- PhD Student, Graduated Spring 2003; presently at LLNL

Giovanni Piredda – PhD Student, will graduate 2004

Vincent Wong – PhD Student, will graduate 2004

Aaron Schwensberg – PhD Student

Colin O'Sullivan Hale – PhD Student

Petros Zerom – PhD Student

Ksenia Dolgaleva – PhD Student

Svetlana Lukishova -- Senior scientist working with group

Nick Lepeshkin -- Post Doc

Robert Boyd -- Professor

Published Papers

Parametric downconversion vs. optical parametric amplification: a comparison of their quantum statistics, E. M. Nagasako, S. J. Bentley and R. W. Boyd, and G. S. Agarwal, J. Mod. Optics, 49, 529 2002.

"Two-Photon" Coincidence Imaging with a Classical Source, R S. Bennink, S. J. Bentley, and R. W. Boyd, Phys. Rev. Lett. 89, 1130601, 2002. (ONR, ARO)

Stabilization of the propagation of spatial solitons, M. S. Bigelow, Q-Han Park, and R. W. Boyd, Phys. Rev. E., 66, 046631, 2002. (AFOSR, ONR, ARO, DoE)

Improved measurement of squeezed light via an eigenmode approach, Ryan S. Bennink and Robert W. Boyd, Phys. Rev. A 66, 053815 (2002). (ONR, ARO)

Influence of damping on the vanishing of the electro-optic effect in chiral isotropic media, G.S. Agarwal and R. W. Boyd, Phys. Rev. A, 67 043821, 2003.

Observation of Ultra-Slow Light Propagation in a Ruby Crystal at Room Temperature M. S. Bigelow, N. N. Lepeshkin, R. W. Boyd, Phys. Rev. Lett. 90, 113903 (2003). A news article published in Nature describing this work can be found at the following web address http://www.nature.com/nsu/030324/030324-4.html

Superluminal and Slow Light Propagation in a Room-Temperature Solid, M. S. Bigelow, N. N. Lepeshkin, and R. W. Boyd, Science, 301, 200, 2003. (ONR, ARO, DoE, AFOSR)

Papers in Review

Superluminal and Ultra-Slow Light Propagation in Room-Temperature Solids, R.W. Boyd, M.S. Bigelow, and N.N. Lepeshkin, to be published in the proceedings of ICOLS 03.

Novel Photonic Materials for Advanced Imaging Applications, R. W. Boyd. Journal of the Korean Physical Society, 43, XXX 2003.

Chirality and Polarization effects in Nonlinear Optics, R. W. Boyd, J. E. Sipe, and P. W. Milonni, submitted to the Journal of Optics A.

Equivalence of Interaction Hamiltonians in the Electric Dipole Approximation, K. Rzazewski and R.W. Boyd, accepted for publication in JMO.

Influence of Radiative Damping on the Optical-Frequency Susceptibility, P.W. Milonni and R.W. Boyd, accepted by PRA.

Filamentation of Ring Beams with Orbital Angular Momentum in Sodium Vapor, M.S. Bigelow, P. Zerom, and R.W. Boyd, submitted to PRL.

Measurement of the Intensity-Dependent refractive Index Using Complete Spatio-Temporal Pulse Characterization, G. Piredda, C. Dorrer, E. M. Kosik, I. A. Walmsley, and R.W. Boyd, submitted to Optics Express. 233. Quantum and Classical Coincidence Imaging, R.S. Bennink, S. J. Bentley, R. W. Boyd, and J. C. Howell, submitted to PRL.

Dramatic Enhancement of Third-Harmonic Generation in 3-D Photonic Crystals, P. Markowicz, H. Tiryaki, H. Pudavar, P. N. Prasad, N.N. Lepeshkin, and R.W. Boyd, in review.

Momentum-position realization of the Einstein-Podolsky-Rosen Paradox, J. C. Howell, R.S. Bennink, S. J. Bentley, and R. W. Boyd, in review.

Conference Reports

Feedback-free hexagon pattern formation with nematic liquid crystals, Svetlana G. Lukishova, Robert W. Boyd, Kenneth L. Marshall, IQEC 2002, 26 June 2002, Moscow, Russia.

Gap soliton effect in a microresonator structure, S. Pereira, P. Chak, J. E. Sipe, J. Heebner; R. W. Boyd, R. S. Bennink and R. W. Boyd, Improved measurement of multimode squeezed light via eigenmode decomposition; Feedback-free kaleidoscope of patterns from nanosceond laser irradiated nematic liquid crystals, S. Lukishova, R. W. Boyd, and K. L. Marshall; Laser-induced cumulative birefringence in nematic liquid crystals, S. Lukishova, R. W. Boyd, and K. L. Marshall; Measurement of the intensity dependent refractive index using complete spatio-temporal ultrashort pulse characterization, G. Piredda, R. W. Boyd, C. Dorrer, E. M. Kosik, and I. A. Walmsley, presented at CLEO/QELS, May 19-24, Long Beach California.

Reducing the Effect of Laser Beam Filamentation, Sean J. Bentley and Robert W. Boyd, presented at OPTO-Canada 2002, Ottawa, Canada, May 10, 2002.

Slow Light in Ruby and in Artificial Materials, Workshop on Quantum Optics, Institute for Theoretical Physics, University of California, Santa Barbara, CA July 23, 2002

Optical Biosensors Based on Whispering Gallery Mode Disk Resonators, J. E. Heebner, N. Lepeshkin, A. Schweinsberg and R. W. Boyd Fifth Workshop on Biosensors and Techniques for Environmental Analysis, Cornell University, May 31 through June 4, 2002.

New Concepts and Materials for Nonlinear Optics, presented at the Atomic, Molecular and Optical Physics Seminar present at SUNY Stony Brook June 11, 2002

Topical Meeting on Nonlinear Optics, Co-sponsored by the Optical Society of America and IEEE LEOS, Maui, Hawaii August 2002: Saturation-induced extra resonances in pump-probe spectroscopy, V. Wong, R. W. Boyd, C. R. Stroud, Jr., and R. S. Bennink and Enhanced Nonlinear Optical Response of 1-D Metal-Dielectric Photonic Band-Gap Structures, R. W. Boyd, N. N. Lepeshkin, A. Schweinsberg, R. S. Bennink, and R. L. Nelson, both accepted for oral presentation.

Slow Light, Fast light, and Optical Solitons in Structured Optical Waveguides, R. W. Boyd and J. E. Heebner, OSA Meeting on Nonlinear Guided Waves, Stresa, Italy, September 2, 2002.

Observation of Slow Light in Ruby, M. S. Bigelow, N. N. Lepeshkin, and R. W. Boyd, Enhanced Nonlinear Optical Response of 1-D Metal-Dielectric Photonic Band-Gap Structures, R. W. Boyd, N. N. Lepeshkin, A. Schweinsberg, R. S. Bennink, and R. L. Nelson, Brillouin Scattering in Media with Sound Dispersion, N. N. Lepeshkin, M. S. Bigelow, R. W. Boyd, A. G. Kaufman, and G. Kurizski, High-Order Modulation Instability, S. J. Bentley, J. E. Heebner, and R. W. Boyd, Saturation-Induced Extra Resonance in Pump-Probe Spectroscopy, V. Wong, R. W. Boyd, C. R. Stroud, Jr., and R. S. Bennink, Feedback Free Pattern Formation in Dye-Doped Nematic Liquid Crystals, S. G. Lukishova, R. W. Boyd, K. L. Marshall, A. Schmid, and N. N. Lepeshkin, OSA Annual Meeting with APS/DLS Laser Science Conference, September 29 – October 3, 2002.

Nanostructured Materials and Devices for Photonics, Robert W. Boyd, presented at the International Symposium on Photonic Science in the 21st Century, a part of the 50th Anniversay annual meeting of the Korean Physical Society, Hanyang University,

Seoul, Korea, October 25, 2002. Similar talks were also presented as Ewha Womans University and Korea University. *

Quantum and Nonlinear Optical Imaging, Presented at the ARO Optics Workshop, October 16, 2002. *

Quantum and Nonlinear Optical Imaging, Presented at the Workshop on Quantum Imaging and Metrology, Pasadena, CA November 14-15, 2002. *

Nanofabrication of Nonlinear Optical Materials and the Development of Ultrasensitive Disk-Microresonator Biosensors Presented at the Physical Sciences Laboratory, University of Maryland, November 20, 2002. *

Slow Light, Enhance Optical Nonlinearities, and Photonic Biosensors based on Quantum Coherence and on Artificial Optical Materials, presented at the 33rd Winter Colloquium on the Physics of Quantum Electronics, Snowbird Utah, January 9, 2003 **

New Materials and Interactions for Nonlinear Optics, presented February 4, 2003 as the Physics Colloquium at Ohio State University.

New Materials and Interactions for Nonlinear Optics, presented February 18, 2003 at Los Alamos National Laboratory.

New Materials and Interactions for Nonlinear Optics, presented as a seminar for first year graduate students at the University of Rochester Department of Physics and Astronomy, April 4, 2003.

Nanostructured Artificial Materials for Nonlinear Optics, Institute of Optics Industrial Asssociates Meeting, April 7, 2003.

Slow Light, Enhance Optical Nonlinearities, and Photonic Biosensors based on Quantum Coherence and on Artificial Optical Materials,, presented April 9, 2003 at the joint Harvard University ITAMP, Atomic, Molecular, and Optical Physics Colloquium.

Nonlinear Optical Physics, Physics Colloquium, San Diego State Unversity, May 2, 2003

Nonlinear Optical Physics, Physics Colloquium, University of California at Berkeley, May 5, 2003

Nonlinear Optical Physics, DAMOP Annual Meeting, Boulder Colorado, May 22, 2003.

Super-resolution by Nonlinear Optical Lithography, S. J. Bentley and R. W. Boyd, Demonstration of a Room-Temperature Single-Photon Source, S. G. Lukishova, A. W. Schmid, A. J. McNamara, R. W. Boyd, and C. R. Stroud, Jr., Quantum and Classical aspects of Coincidence Imaging, R. S. Bennink, S. J. Bentley, and R. W. Boyd, Nonlinear Optical Properties of Nobel Metals at the Interband Transition Threshold, N. Lepeshkin, G. Piredda, A. Schweinsberg, and R. W. Boyd, Electromagnetically Induced Transparency and Absorption in a Single Raman Spectrum, R. S. Bennink, A. M. Marino, V. Wong, C. R. Stroud, R. W. Boyd, and F. A. Narducci, Graphical Solution of Coherent Raman Systems Using the Bloch Sphere, R. S. Bennink, C. R. Stroud, Jr., and R. W. Boyd, Observation of Superluminal Pulse Propagation in Alexandrite, M. S. Bigelow, N. N. Lepeshkin, and R. W. Boyd, CLEO/QELS, Baltimore, Maryland, June 1-6, 2003.

Honeycomb Pattern Formation by Laser-Beam Filamentation in Atomic Sodium Vapor. R.S. Bennink, V. Wong, A.M. Marino, D.L. Aronstein, R.W. Boyd, C.R. Stroud, Jr., S. Lukishova, and D.J. Gauthier, European Quantum Electronics Conference, Munich Germany, June 24, 2003.

Chirality and Polarization Effects in Nonlinear Optics, R. W. Boyd, presented at the ICO Conference on Polarization Optics, Joensuu, Finland, June 30, 2003.

Ultra-Slow Light Propagation in Room Temperature Solids, R. W. Boyd, presented at the Laser-Optics Conference, St. Petersburg, Russia, July 3, 2003.

Ultra-Slow Light Propagation in Room Temperature Solids, R. W. Boyd, M. S. Bigelow, and N. N. Lepeshkin, presented at the International Conference on Laser Spectroscopy, Palm Cove, Australia, July 13-18, 2003.